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**MALADJUSTMENT OF KIDNEYS TO MICROGRAVITY:  
DESIGN OF MEASURES TO REDUCE THE LOSS OF CALCIUM**

**Final Report**

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## ABSTRACT

Losses of skeletal calcium and body fluids occur during prolonged exposure to microgravity. The kidney plays a major role in regulating the physiological functions involved. Relative to this regulatory function, the kidney performs three operations: filtration of blood plasma through the glomeruli, reabsorption, and secretion of fluid and electrolytes so that needed components are retained and only waste is eliminated in the urine.

Using data published in "Biomedical Results from Skylab" (1), we performed new calculations that reflect more directly the operations of the kidney in the handling of calcium, sodium, chloride, potassium and phosphate during space flight. These calculations revealed that the fraction of filtered calcium that was rejected by renal tubules and excreted in the urine increased by 71%, from 1.77% (preflight) to 3.02% (in-flight) of the filtered load. This represents a large absolute increase because the total filtered amount is huge. Because the tubular rejection fraction of other ions increased relatively less than that of calcium, we postulate the inflight development of a specific renal defect that causes an excessive loss of calcium in urine and thereby contributes to the weakening of bones.

Because the reabsorption of glomerular filtrate (the conservation of body fluids and electrolytes by the kidney) depends upon the energy of adenosinetriphosphate (ATP) and enzymes that liberate its energy, we propose that an induction of the major renal enzyme system involved, sodium and potassium-dependent adenosinetriphosphatase, may improve the reabsorption of sodium directly and calcium indirectly and thereby lead to improved hydration and reduced calcium loss.

## INTRODUCTION

Because of the known detrimental shifts of fluids and electrolytes, particularly calcium losses, that occur under conditions of microgravity, we undertook an evaluation of renal function studies during the Skylab flights and of renal handling of important ions. Using data published in "Biomedical Results from Skylab" (1), we performed new calculations that reflect more directly the operations of the kidneys of astronauts under conditions of microgravity.

To make this report clear to the nonspecialist, we now give a brief summary of pertinent renal physiology, in part derived from Pitts (2). The two kidneys weigh about 300 grams and thus constitute 0.4% of total body weight. In humans, each kidney is composed of about one million units called nephrons, which function in parallel. Each nephron begins with a glomerulus (microscopic sieve) attached to a tubule. Fluid filtered by the glomeruli passes through the renal tubules, to collecting ducts and eventually to the urinary bladder. The kidneys receive the greatest blood flow, in proportion to weight, of any organ of the body. Renal blood flow is equal to 20-25% of cardiac output or about 2000 liters per day. Urine formation starts with the filtration of blood plasma through the glomeruli at the rate of about 200 liters per day. The renal tubules reabsorb needed components of the glomerular filtrate, which contain most constituents of blood plasma excluding protein, and add to the filtrate undesirable products by secretion. The net result is excretion of waste in urine at an average rate of two liters per day. Thus, about 99% of glomerular filtrate is reabsorbed. Given the fact that an average adult has 40 liters of fluid in the body, the internal autodialysis of all body fluids through the kidneys takes place five times every 24 hours (200 liters of glomerular filtrate/40=5). The net result of renal filtration, reabsorption and secretion is the regulation of composition, within narrow limits compatible with life, of body fluids, often referred to as the constant internal environment.

## METHODS

Glomerular filtration rates (GFR) and renal handling of ions were estimated (2,3) based on plasma and urinary concentrations obtained from published data from the nine crewmen who participated in Skylab flights (Tables 1 and 2). Where appropriate, plasma concentrations of substances obtained at different times were averaged to match the periods of urinary excretion data available.

The renal clearance of a substance is defined as the number of milliliters of plasma completely cleared of that substance in one minute. If the substance is completely filterable through glomeruli, that is, it is neither reabsorbed nor secreted, if it has no effect on renal function, and if it can be accurately measured in plasma and urine, then its clearance can be taken as a valid measure of GFR. Normal GFR per 1.73 square meters of body surface area, standard for an adult, averages 125 ml/min in men and 110 ml/min in women. In healthy persons, GFR is remarkably stable from day to day over a period of years.

The formula for calculation of renal clearance is  $U \times V/P$ , where U and P represent concentrations of the substance in urine and plasma (mg/ml) respectively, and V represents urine formation rate in ml/min. If the clearance of a given substance is larger than the simultaneous GFR, that substance is said to be "secreted" by the tubules of the kidney. If clearance of a substance is smaller than GFR, the substance is said to

be "reabsorbed." It should be noted that, in the absence of more detailed studies, the clearance of a substance is a net figure and does not take into account simultaneous secretion and reabsorption that might also be taking place.

The standard method of determination of GFR is by measurement of inulin clearance following intravenous infusion. Inulin is a high (5,000) molecular weight polysaccharide that is completely filterable and is neither secreted nor absorbed by the kidney. Obviously, this method cannot be used during space flight. Instead, measurement of endogenous creatinine clearance, which agrees reasonably well with the inulin clearance, is usually taken as an approximate measure of GFR and was used in our calculations. Creatinine is a product of muscle creatine phosphate; its production is constant and is proportional to muscle mass. Renal elimination of creatinine is also constant. The agreement of GFR as measured by inulin and by creatinine clearances results from the balance of two errors: 1) the analysis method slightly overestimates the creatinine concentration in plasma (but not in urine), and this gives the appearance of a lower creatinine clearance; and 2) the true clearance of creatinine is slightly higher than GFR because of tubular secretion. These are the limitations in using creatinine clearance as an approximate measure of GFR in these studies.

Filtration rate of an ion (mg/min) through glomeruli was calculated by multiplying its filterable concentration in plasma (mg/ml) by the GFR (ml/min). Because 40% of plasma calcium is bound to plasma proteins, which are too large to pass through the glomeruli, the filterable fraction of calcium was taken as 60% of total plasma calcium. Phosphate was assumed 90% filterable. Virtually all plasma sodium, potassium and chloride are freely filterable.

The tubular reabsorption rate (mg/min) of an ion is its filtration rate (mg/min) minus its excretion rate (mg/min). Tubular rejection fraction or fractional excretion (%) was calculated by the formula: Excretion rate (mg/min)/ filtration rate (mg/min) x 100. This yields the percentage of the filtered quantity of a given ion that escaped tubular reabsorption.

## RESULTS

Renal function data calculated from Tables 1 and 2 are shown in Table 3. Creatinine clearances proved remarkably stable throughout the missions, indicating intact renal vascular autoregulatory mechanisms that control the GFR in the face of the well known circulatory disturbances and body fluid shifts that occur during space flight (4-6). In flight, GFR's held within 2-3% of the preflight values and fell only a modest 9% during the 60-85 day flight period.

Tubular reabsorption of individual ions was depressed during flight and reverted postflight to baseline, preflight values (Fig. 1). Peak fractional excretion rose 71% (from 1.77% to 3.02%) for calcium, 12% for phosphate, 38% for chloride and 40% for sodium. This indicates a generalized increased tubular rejection of several ionic components of the glomerular filtrate with a relative selectivity for calcium.

The data for renal handling of calcium are plotted in Figure 2. The curves for fractional excretion and urinary excretion rate of calcium were similar: the former exhibited a smoother natural progression, suggesting that this was the mechanism for increased calcium loss in the urine. Increased fractional excretion coincided with a

slight but significant rise in plasma calcium concentration (peak 6%). Filtered and reabsorbed calcium increased (peak 8-9%) during flight and paralleled the creatinine clearance curve throughout. Thus, the increased fractional excretion of calcium during flight was the dominant finding.

To see more clearly the mechanism of tubular transport of calcium, in Figure 3 we have plotted renal calcium handling adjusted per 100 ml of GFR. The curve for the urinary calcium excretion rate resembled more closely the curve for fractional calcium excretion than that shown in Figure 2. The adjusted filtration and reabsorption rates of calcium remained parallel but became more stable than those shown in Figure 2, and peak increases during flight were only 4-5%. This is further evidence that the calcium excreted in urine appears there as a result of diminished tubular reabsorption.

The urinary excretion of 0.29 gm of calcium per day during the Skylab flights was nearly twice that of control values of 0.16 gm per day. Thus, 7.8 to 11.05 gm of calcium were lost during 59 day and 84 day Skylab flights respectively. These amounts are equal to more than the total of extraskeletal intracellular and extracellular calcium stores.

## DISCUSSION

The outstanding finding of our study is that renal tubular reabsorption of calcium abruptly diminished during space flight and rapidly returned to control levels after landing. This resulted in urinary excretion of 0.29 gm of calcium per day during flight, up from 0.16 gm per day control rate. The net total calcium loss attributable to the kidney during the Skylab flights of 59 to 84 days equaled 7.8 gm to 11.05 gm respectively. The crewmen had an adequate average dietary intake of 0.73 gm calcium per day but went into negative calcium balance because fecal calcium excretion also increased (1,7). The calcium-wasting by the kidney is further demonstrated by the lack of renal conservation of calcium in the face of the increased fecal calcium losses.

To place the magnitude of the calcium loss in perspective, it is essential to realize that all extracellular body fluids contain only about 1 gm of calcium, cells contain 5 gm, and bone contains a total of 1,200 gm (3). Thus, any sizeable calcium loss, like that which occurred during the Skylab flights, must come eventually from bone. Calcium homeostasis involves continuous mineral turnover in bone, absorption from food and reabsorption by the kidney. Overall calcium metabolism is primarily set to maintain a constant calcium concentration in extracellular fluid, even at the expense of bone density. Absorption from the gut is controlled by vitamin D, bone resorption and renal reabsorption are promoted by parathyroid hormone and inhibited by calcitonin (3,8).

Based on the above considerations, options for prevention of calcium loss are: 1) increase intake and/or decrease losses of calcium from the gut; 2) decrease calcium loss from bone; and 3) decrease calcium loss from the kidney. Relative to option 1, stable and adequate calcium intake during Skylab flights did not prevent negative calcium balance (1,7). In fact, there was an increased amount of calcium lost in feces (7). Enhancement of calcium absorption from food deserves further study.

Decreased egress of calcium from bone appears to be under most intensive investigation at present as a solution to bone demineralization during space flight. In our opinion, producing a halt to bone resorption without increased absorption from the gut and reduced loss via the kidneys would lead to a reduced intracellular and

extracellular calcium concentration. Since calcium is required for muscular contraction and nerve conduction, inadequate calcium levels may lead to increased weakness and atrophy, already a problem during space flight (9). Diminished supply of calcium to the heart could lead to impairment of cardiac output and to irregularities of heart rhythm (arrhythmias) that could result in sudden death.

Relative to the third option, reversal of the acquired defect in tubular reabsorption of calcium would be a desirable solution to the excessive calcium loss during space flight. Because renal calcium reabsorption is in part dependent upon the transport of sodium, we propose that an induction of renal sodium and potassium-dependent adenosinetriphosphatase (Na and K ATPase), an enzyme system that allows the use of adenosine triphosphate (ATP) for ion transport (10), would improve tubular reabsorption of sodium directly and that of calcium secondarily. In addition to calcium conservation, this maneuver would improve reabsorption of sodium, chloride and water, all of which are also excessively lost during space flight. Methods for induction of renal Na and K ATPase deserve further investigation in an attempt to prevent osteoporosis and fluid and electrolyte loss associated with space travel. The magnitude of renal-related calcium losses, coupled with the fact that Skylab astronauts had adequate calcium intake and excessive fecal calcium losses, make it wise to consider ways in which renal losses of calcium can be curtailed.

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TABLE 1.-FROM REFERENCE 1.

TABLE 23-IX.—*Skylab Summary, Urine Biochemical Results (9 Crewmen)*

Units		(Mean $\pm$ Standard error)						
		Preflight day		In-flight day			Postflight day	
		1-28	29-59	60-85	1-6	7-13	14-18	
meq/TV	Sodium	160.0 $\pm$ 3.0	174.0 $\pm$ 3.0	190.0 $\pm$ 7.0	199.0 $\pm$ 6.0	121.0 $\pm$ 11.0	170.0 $\pm$ 6.0	173.0 $\pm$ 11.0
meq/TV	Potassium	74.0 $\pm$ 1.0	82.0 $\pm$ 2.0	80.0 $\pm$ 2.0	81.0 $\pm$ 3.0	65.0 $\pm$ 4.0	76.0 $\pm$ 4.0	82.0 $\pm$ 5.0
meq/TV	Chloride	148.0 $\pm$ 4.0	162.0 $\pm$ 5.0	177.0 $\pm$ 6.0	180.0 $\pm$ 5.0	116.0 $\pm$ 11.0	160.0 $\pm$ 6.0	164.0 $\pm$ 11.0
mg/TV	Creatinine	1955.0 $\pm$ 20.0	2079.0 $\pm$ 40.0	2104.0 $\pm$ 55.0	2081.0 $\pm$ 31.0	2005.0 $\pm$ 95.0	2037.0 $\pm$ 78.0	1969.0 $\pm$ 109.0
mOsmoles	Osmolality	650.0 $\pm$ 17.0	789.0 $\pm$ 27.0	791.0 $\pm$ 19.0	717.0 $\pm$ 24.0	593.0 $\pm$ 60.0	549.0 $\pm$ 49.0	584.0 $\pm$ 66.0
meq/TV	Calcium	8.0 $\pm$ 0.2	14.4 $\pm$ 0.8	14.5 $\pm$ 0.8	11.8 $\pm$ 0.4	11.2 $\pm$ 1.6	8.8 $\pm$ 1.0	8.3 $\pm$ 1.0
mg/TV	Phosphates	1045.0 $\pm$ 15.0	1270.0 $\pm$ 27.0	1196.0 $\pm$ 35.0	1181.0 $\pm$ 30.0	934.0 $\pm$ 55.0	1029.0 $\pm$ 55.0	1031.0 $\pm$ 50.0
mg/TV	Uric Acid	969.0 $\pm$ 15.0	899.0 $\pm$ 22.0	934.0 $\pm$ 38.0	884.0 $\pm$ 33.0	884.0 $\pm$ 41.0	929.0 $\pm$ 50.0	942.0 $\pm$ 53.0
meq/TV	Magnesium	8.9 $\pm$ 0.1	10.8 $\pm$ 0.2	9.4 $\pm$ 0.4	8.7 $\pm$ 0.5	7.7 $\pm$ 0.5	9.1 $\pm$ 0.4	9.1 $\pm$ 0.4
μg/TV	Cortisol	54.3 $\pm$ 4.1	94.4 $\pm$ 4.8	83.6 $\pm$ 4.0	90.2 $\pm$ 5.3	69.5 $\pm$ 5.8	63.3 $\pm$ 6.0	76.6 $\pm$ 8.0
μg/TV	Aldosterone	11.3 $\pm$ 1.1	32.8 $\pm$ 2.2	22.4 $\pm$ 1.7	30.0 $\pm$ 3.1	18.6 $\pm$ 4.3	11.8 $\pm$ 3.0	11.4 $\pm$ 3.3
μg/TV	Epinephrine	27.2 $\pm$ 4.6	24.3 $\pm$ 1.4	21.3 $\pm$ 1.7	38.1 $\pm$ 3.3	37.2 $\pm$ 3.1	33.7 $\pm$ 3.4	37.5 $\pm$ 7.2
μg/TV	Norepinephrine	69.4 $\pm$ 6.0	59.9 $\pm$ 2.0	66.7 $\pm$ 4.0	65.2 $\pm$ 6.4	99.4 $\pm$ 6.2	88.8 $\pm$ 6.4	89.6 $\pm$ 6.6
mμ/TV	Antidiuretic hormone	50.3 $\pm$ 10.0	41.9 $\pm$ 4.3	24.1 $\pm$ 2.4	20.3 $\pm$ 2.5	46.5 $\pm$ 10.0	25.6 $\pm$ 8.0	31.0 $\pm$ 8.2
mg/TV	Total 17 Hydroxy-corticosteroids	6.1 $\pm$ 0.4	6.2 $\pm$ 0.4	6.5 $\pm$ 0.3	6.2 $\pm$ 1.0	5.2 $\pm$ 0.5	5.1 $\pm$ 0.4	5.2 $\pm$ 0.8
mg/TV	Total 17 Ketosteroids	7.0 $\pm$ 0.5	10.3 $\pm$ 0.4	10.8 $\pm$ 0.5	13.5 $\pm$ 1.3	7.0 $\pm$ 0.7	7.4 $\pm$ 0.5	7.6 $\pm$ 0.6

\*  $P \leq 0.05$ .

TV Total volume 24h

TABLE 2.-FROM REFERENCE 1.

TABLE 23-V.—Skylab Summary, Plasma Biochemical Results (9 Crewmen)

		(Mean $\pm$ Standard error)							
No.		Sodium <sup>a</sup>	Potassium	Chloride	Creatinine	Glucose	Osmolality	Calcium	Phosphate
		meq/liter	meq/liter	meq/liter	mg pct.	mg pct.	mOsmoles	mg pct.	mg pct.
36	Preflight	141 $\pm$ 0.7	4.12 $\pm$ 0.04	97.7 $\pm$ 0.5	1.26 $\pm$ 0.03	86.6 $\pm$ 0.03	290 $\pm$ 0.8	9.7 $\pm$ 0.05	3.4 $\pm$ 0.1
<i>Mission day</i>									
9	3, 4	139 $\pm$ 2	4.26 $\pm$ 0.08	96.8 $\pm$ 0.7	1.81 $\pm$ 0.03	90.3 $\pm$ 2.4	289 $\pm$ 1	<sup>a</sup> 10.4 $\pm$ 0.1	3.7 $\pm$ 0.3
8	5, 6	<sup>a</sup> 137 $\pm$ 2	4.30 $\pm$ 0.14	96.9 $\pm$ 0.8	1.27 $\pm$ 0.03	86.7 $\pm$ 1.8	<sup>a</sup> 287 $\pm$ 1	<sup>a</sup> 10.2 $\pm$ 0.1	<sup>a</sup> 3.6 $\pm$ 0.3
6	13, 14	137 $\pm$ 1	4.41 $\pm$ 0.15	<sup>a</sup> 94.7 $\pm$ 1.1	1.28 $\pm$ 0.03	86.7 $\pm$ 1.8	286 $\pm$ 2	<sup>a</sup> 10.2 $\pm$ 0.1	<sup>a</sup> 3.9 $\pm$ 0.3
6	20, 21	140 $\pm$ 1	4.25 $\pm$ 0.11	95.7 $\pm$ 0.8	1.35 $\pm$ 0.03	87.0 $\pm$ 1.8	289 $\pm$ 2	<sup>a</sup> 10.1 $\pm$ 0.2	<sup>a</sup> 3.4 $\pm$ 0.1
6	27, 30	<sup>a</sup> 138 $\pm$ 0.8	4.25 $\pm$ 0.10	<sup>a</sup> 95.2 $\pm$ 0.8	1.27 $\pm$ 0.03	84.3 $\pm$ 2.3	<sup>a</sup> 287 $\pm$ 2	<sup>a</sup> 10.4 $\pm$ 0.1	<sup>a</sup> 3.9 $\pm$ 0.3
6	38	<sup>a</sup> 136 $\pm$ 2	<sup>a</sup> 4.05 $\pm$ 0.15	93.5 $\pm$ 1.2	1.31 $\pm$ 0.07	<sup>a</sup> 80.1 $\pm$ 2.5	<sup>a</sup> 280 $\pm$ 4	10.1 $\pm$ 0.2	<sup>a</sup> 3.1 $\pm$ 0.5
6	45, 48	<sup>a</sup> 137 $\pm$ 2	4.30 $\pm$ 0.13	94.5 $\pm$ 0.7	1.34 $\pm$ 0.03	<sup>a</sup> 84.4 $\pm$ 1.4	287 $\pm$ 3	<sup>a</sup> 10.1 $\pm$ 0.1	<sup>a</sup> 3.8 $\pm$ 0.1
6	58, 59	<sup>a</sup> 137 $\pm$ 2	4.19 $\pm$ 0.13	94.0 $\pm$ 1.5	1.38 $\pm$ 0.12	<sup>a</sup> 81.8 $\pm$ 2.2	286 $\pm$ 4	<sup>a</sup> 10.1 $\pm$ 0.2	<sup>a</sup> 3.8 $\pm$ 0.2
3	73	139 $\pm$ 2	3.75 $\pm$ 0.20	94.6 $\pm$ 1.2	1.51 $\pm$ 0.05	80.9 $\pm$ 2.2	284 $\pm$ 2	10.1 $\pm$ 0.3	<sup>a</sup> 3.9 $\pm$ 0.2
3	82	137 $\pm$ 0.6	4.19 $\pm$ 0.06	95.8 $\pm$ 0.2	1.54 $\pm$ 0.03	<sup>a</sup> 81.0 $\pm$ 1.2	<sup>a</sup> 285 $\pm$ 2	10.1 $\pm$ 0.1	3.6 $\pm$ 0.1
<i>Recovery (R)</i>									
9	R + 0	139 $\pm$ 1	4.18 $\pm$ 0.05	<sup>a</sup> 96.2 $\pm$ 1.0	1.28 $\pm$ 0.05	<sup>a</sup> 100.5 $\pm$ 2.6	289 $\pm$ 1	<sup>a</sup> 10.0 $\pm$ 0.1	<sup>a</sup> 3.9 $\pm$ 0.2
9	R + 1	139 $\pm$ 1	4.10 $\pm$ 0.08	<sup>a</sup> 96.4 $\pm$ 1.0	1.31 $\pm$ 0.06	92.3 $\pm$ 2.8	289 $\pm$ 1	<sup>a</sup> 10.1 $\pm$ 0.1	<sup>a</sup> 3.6 $\pm$ 0.03
9	R + 3, 4	139 $\pm$ 1	4.02 $\pm$ 0.13	96.9 $\pm$ 1.0	1.26 $\pm$ 0.06	<sup>a</sup> 90.5 $\pm$ 1.4	<sup>a</sup> 294 $\pm$ 2	9.8 $\pm$ 0.1	3.4 $\pm$ 0.2
6	R + 14	141 $\pm$ 0.8	4.05 $\pm$ 0.05	97.7 $\pm$ 1.6	1.33 $\pm$ 0.09	85.4 $\pm$ 0.7	289 $\pm$ 2	<sup>a</sup> 9.4 $\pm$ 0.1	2.8 $\pm$ 0.2

<sup>a</sup> Corrected for Na-EDTA.<sup>a</sup>  $P \leq 0.05$ .

TABLE 23-VI.—Skylab Summary, Plasma Biochemical Results (9 Crewmen)

		(Mean $\pm$ Standard error)						
No.		Cortisol	Angiotensin I	Aldosterone	ACTH	Insulin	HGH	PTH
		$\mu\text{g}/100 \text{ ml}$	$\text{ng}/\text{ml per hour}$	$\text{pg}/100 \text{ ml}$	$\text{pg}/\text{ml}$	$\mu\text{U}/\text{ml}$	$\text{ng}/\text{ml}$	$\text{ng}/\text{ml}$
39	Preflight	12.2 $\pm$ 0.7	0.77 $\pm$ 0.14	180 $\pm$ 25	35.7 $\pm$ 3.3	17 $\pm$ 0.6	1.3 $\pm$ 0.2	17 $\pm$ 1
<i>Mission Day</i>								
9	3, 4	12.7 $\pm$ 1.6	1.09 $\pm$ 0.24	176 $\pm$ 58	<sup>a</sup> 15.2 $\pm$ 4.9	15 $\pm$ 2	<sup>a</sup> 2.1 $\pm$ 0.5	17 $\pm$ 2
8	5, 6	<sup>a</sup> 14.8 $\pm$ 1.0	1.75 $\pm$ 0.42	163 $\pm$ 75	26.5 $\pm$ 9.2	18 $\pm$ 6	1.2 $\pm$ 0.3	16 $\pm$ 3
6	13, 14	13.4 $\pm$ 1.7	.91 $\pm$ 0.28	252 $\pm$ 65	33.0 $\pm$ 8	18 $\pm$ 3	1.5 $\pm$ 0.2	14 $\pm$ 1
6	20, 21	12.3 $\pm$ 1.5	.52 $\pm$ 0.12	163 $\pm$ 90	<sup>a</sup> 11.9 $\pm$ 4	<sup>a</sup> 8 $\pm$ 1	1.2 $\pm$ 0.3	20 $\pm$ 4
6	27, 30	13.6 $\pm$ 2.1	.45 $\pm$ 0.16	204 $\pm$ 88	32.0 $\pm$ 7	20 $\pm$ 3	3.2 $\pm$ 2.0	14 $\pm$ 2
6	38	13.7 $\pm$ 1.0	.72 $\pm$ 0.36	94 $\pm$ 17	17.7 $\pm$ 11.6	<sup>a</sup> 10 $\pm$ 1	1.1 $\pm$ 0.3	15 $\pm$ 2
6	45, 48	14.3 $\pm$ 1.3	.37 $\pm$ 0.10	118 $\pm$ 7	<sup>a</sup> 12.1 $\pm$ 5.3	<sup>a</sup> 9 $\pm$ 2	1.5 $\pm$ 0.5	18 $\pm$ 4
6	58, 59	<sup>a</sup> 13.5 $\pm$ 0.7	<sup>a</sup> 1.11 $\pm$ 0.51	148 $\pm$ 31	32.3 $\pm$ 18.7	<sup>a</sup> 9 $\pm$ 2	1.6 $\pm$ 0.4	18 $\pm$ 3
3	73	14.5 $\pm$ 3.4	.27 $\pm$ 0.08	117 $\pm$ 39		9 $\pm$ 4	0.6 $\pm$ 0.1	24 $\pm$ 2
3	82	<sup>a</sup> 16.1 $\pm$ 0.6	.32 $\pm$ 0.04	142 $\pm$ 17		11 $\pm$ 4	0.7 $\pm$ 0.1	25 $\pm$ 2
<i>Recovery (R)</i>								
9	R + 0	13.2 $\pm$ 2.1	.71 $\pm$ 0.23	215 $\pm$ 74	23.8 $\pm$ 6.3	20 $\pm$ 3	<sup>a</sup> 2.9 $\pm$ 0.6	17 $\pm$ 2
9	R + 1	10.8 $\pm$ 1.0	<sup>a</sup> 2.15 $\pm$ 0.55	<sup>a</sup> 478 $\pm$ 77	<sup>a</sup> 24.0 $\pm$ 7.5	20 $\pm$ 2	<sup>a</sup> 2.8 $\pm$ 0.8	19 $\pm$ 3
9	R + 3, 4	13.7 $\pm$ 3.0	.86 $\pm$ 0.45	<sup>a</sup> 357 $\pm$ 65	<sup>a</sup> 23.3 $\pm$ 2.4	18 $\pm$ 2	<sup>a</sup> 2.6 $\pm$ 0.8	19 $\pm$ 3
9	R + 13, 14	10.6 $\pm$ 0.7	<sup>a</sup> 1.14 $\pm$ 0.05	153 $\pm$ 35	38.2 $\pm$ 13.9	17 $\pm$ 3	1.2 $\pm$ 0.2	18 $\pm$ 4

<sup>a</sup>  $P \leq 0.05$ .

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TABLE 3.-GLOMERULAR FILTRATION RATE (CREATININE CLEARANCE) AND RENAL ELECTROLYTE TRANSPORT IN 9 SKYLAB CREWMAN. DATA RE-CALCULATED FROM TABLES 1 AND 2.

SUBSTANCE	FUNCTION	UNITS	PREFLIGHT DAY		IN FLIGHT DAYS			POSTFLIGHT DAYS		
			1-28	29-59	60-85	1-6	7-13	14-18		
Creatinine	Urinary excretion rate (UV)	mg/min	1.3576	1.4438	1.4611	1.4451	1.3924	1.4146	1.3674	
	Plasma concentration (P)	mg/ml	0.0126	0.0130	0.0133	0.0148	0.0128	0.0128	0.0133	
Calcium	Clearance (UV/P)	ml/min	108	111	110	98	109	109	103	
	Plasma concentration (total)	mg/ml	0.0970	0.1030	0.1010	0.1010	0.1000	0.1000	0.0940	
Calcium	Plasma concentration (60%)	mg/ml	0.0582	0.0618	0.0606	0.0606	0.0600	0.0600	0.0564	
	Filtration rate	mg/min	6.2856	6.8598	6.6660	5.9388	6.5400	6.5400	5.8092	
Calcium	Reabsorption rate	mg/min	6.1745	6.6598	6.4646	5.7749	6.3844	6.3844	5.6939	
	Fractional Reabsorption	%	98.23	97.08	96.92	97.24	97.62	97.62	98.02	
Calcium	Excretion rate	mg/min	0.1111	0.2000	0.2014	0.1639	0.1556	0.1556	0.1153	
	Fractional excretion	%	1.77	2.92	3.02	2.76	2.38	2.38	1.98	
Phosphate	Plasma concentration (total)	mg/ml	0.0340	0.0370	0.0345	0.0377	0.0362	0.0362	0.0280	
	Plasma concentration (90%)	mg/ml	0.0306	0.0333	0.0311	0.0339	0.0326	0.0326	0.0252	
Phosphate	Filtration rate	mg/min	3.3048	3.6963	3.4210	3.3222	3.5534	3.5534	2.5956	
	Reabsorption rate	mg/min	2.5791	2.8144	2.5904	2.5021	2.9048	2.9048	1.8796	
Phosphate	Fractional reabsorption	%	78.0	76.1	75.7	75.3	75.3	75.3	72.4	
	Excretion rate	mg/min	0.7257	0.8819	0.8306	0.8201	0.6486	0.7146	0.7160	
Chloride	Fractional excretion	%	22.0	23.9	24.3	24.7	18.3	18.3	27.6	
	Plasma concentration	mM	97.7	95.9	94.0	94.8	96.5	96.5	97.7	
Chloride	Filtration rate	μEq/min	10,552	10,645	10,340	9,290	10,519	10,519	9,991	
	Reabsorption rate	μEq/min	10,449	10,532	10,217	9,165	10,438	10,438	9,877	
Chloride	Fractional reabsorption	%	99.03	98.94	98.81	98.65	99.23	99.23	98.86	
	Excretion rate	μEq/min	103	113	123	125	81	111	114	
Sodium	Fractional excretion	%	0.97	1.06	1.19	1.35	0.77	0.77	1.14	
	Plasma concentration	mM	141	138	137	138	139	139	141	
Sodium	Filtration rate	μEq/min	15,228	15,318	15,070	13,524	15,151	15,151	14,523	
	Reabsorption rate	μEq/min	15,117	15,197	14,937	13,386	15,067	15,067	14,403	
Sodium	Fractional reabsorption	%	99.27	99.21	99.12	98.98	99.45	99.45	99.17	
	Excretion rate	μEq/min	111	121	133	138	89	118	120	
Potassium	Fractional excretion	%	0.73	0.79	0.88	1.02	0.55	0.55	0.83	
	Plasma concentration	mM	4.12	4.29	4.18	4.04	4.10	4.10	4.05	
Potassium	Filtration rate	μEq/min	445	477	459	396	447	447	417	
	Excretion rate	μEq/min	51.4	56.9	55.6	56.3	45.1	52.8	56.9	
Sodium/ Potassium	Fractional excretion	%	11.55	11.93	12.11	14.22	10.09	10.09	13.65	
	Excretion rate/ Excretion rate	Ratio	2.16	2.12	2.38	2.45	1.86	2.25	2.11	

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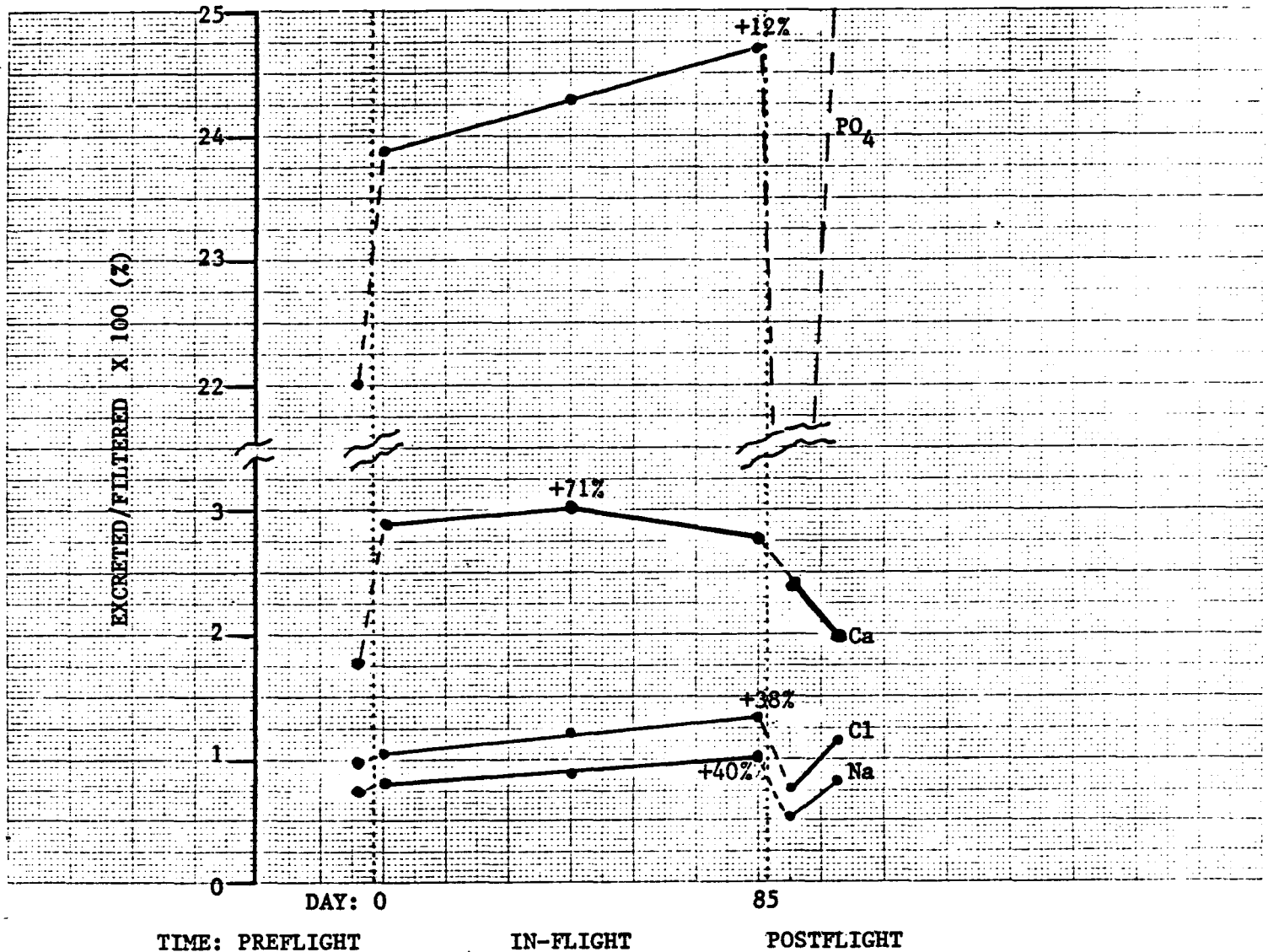


Figure 1. Renal function of nine Skylab crewmen: Fractional excretion of calcium, phosphate, sodium, and chloride. The data indicate filtered fractions of these ions that escaped reabsorption and were excreted in urine. Peak percent changes shown in the figure are relative to preflight values.

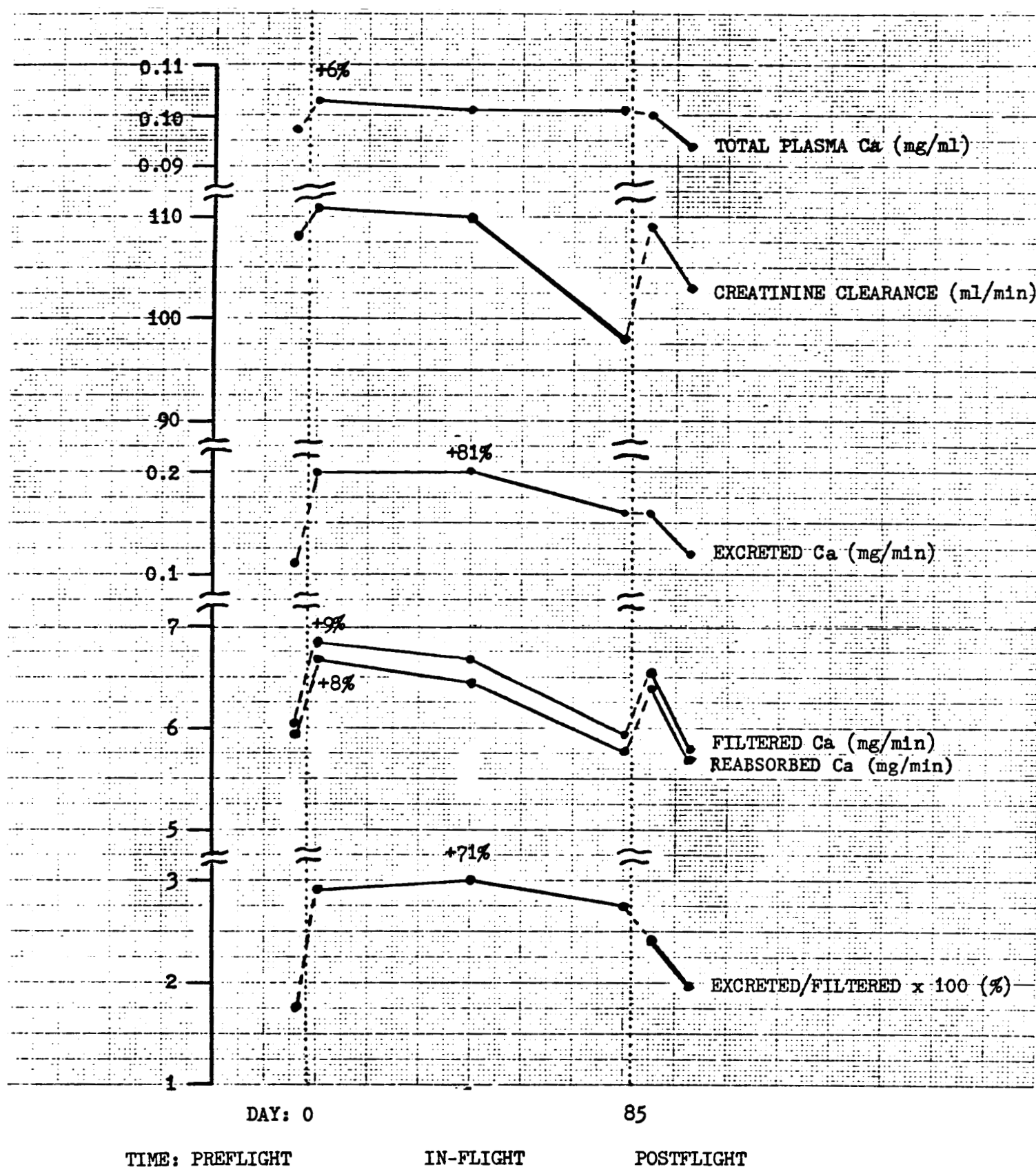


Figure 2. Plasma calcium concentration, GFR, and renal handling of calcium in nine Skylab crewmen. Peak percent changes indicated in the figure are relative to preflight values.

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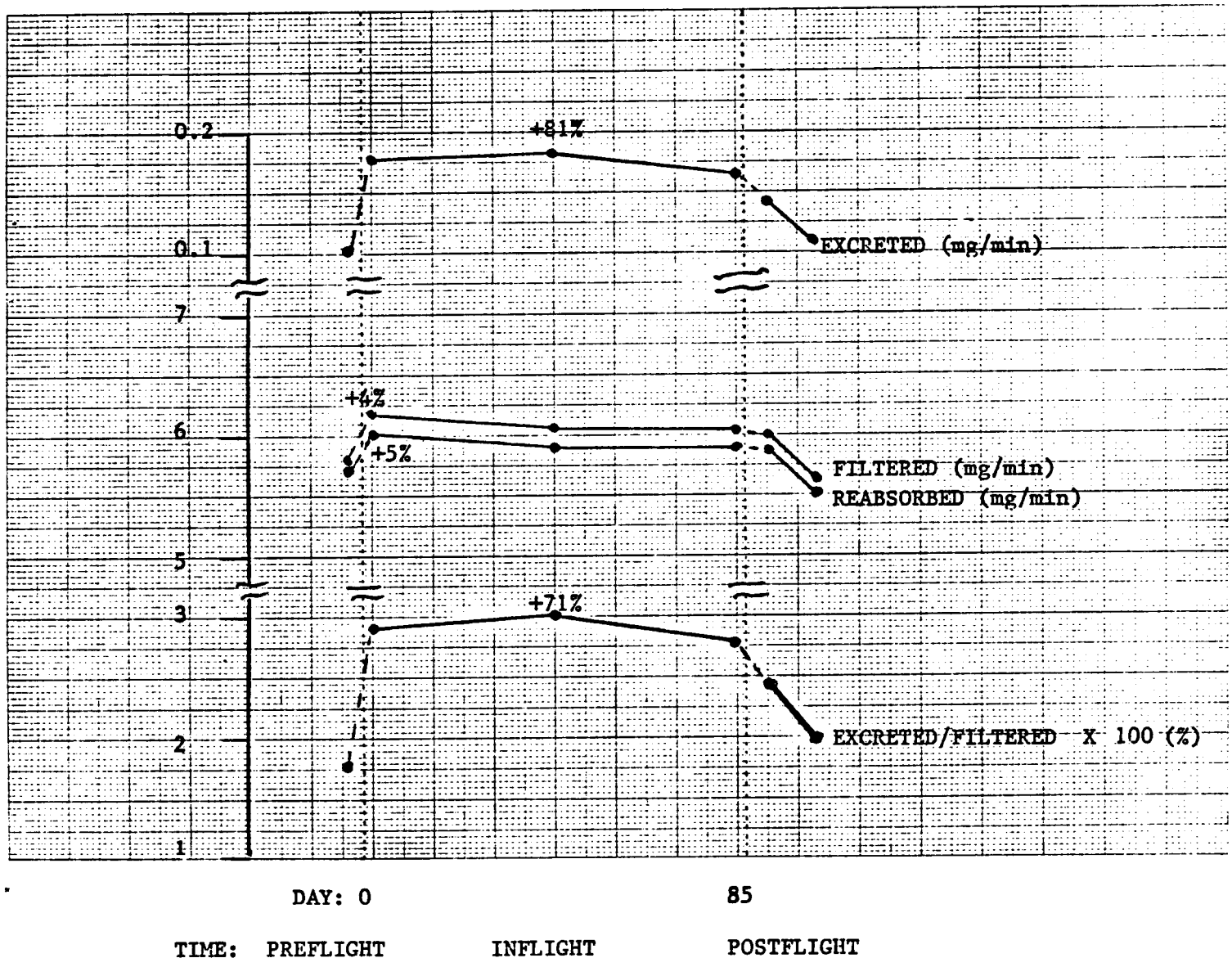


Figure 3. Renal handling of calcium per 100 ml/min GFR in nine Skylab crewmen. Peak percent changes indicated in the figure are relative to preflight values.

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